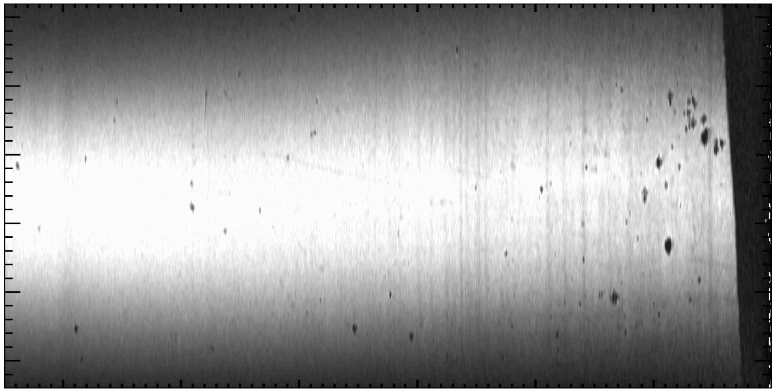
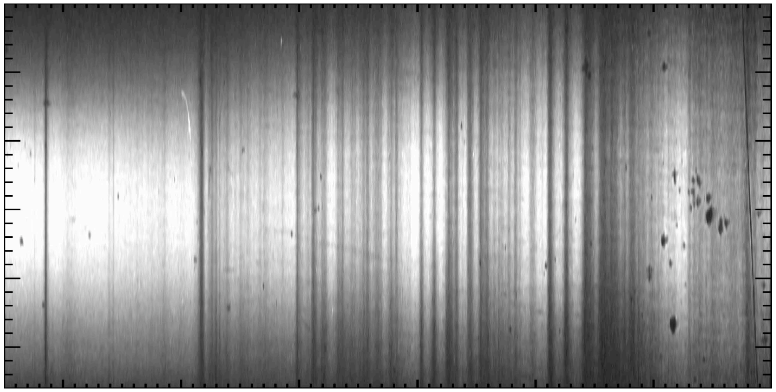
Opacity measurements at Z

Opacity Workshop
Los Alamos National Laboratory
May 5, 2005

without Fe



with Fe + Mg



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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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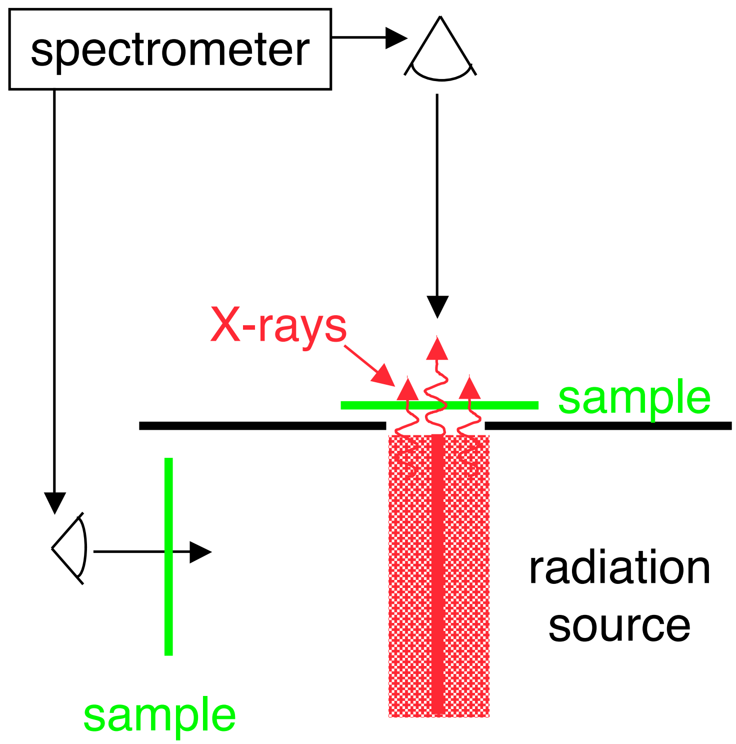
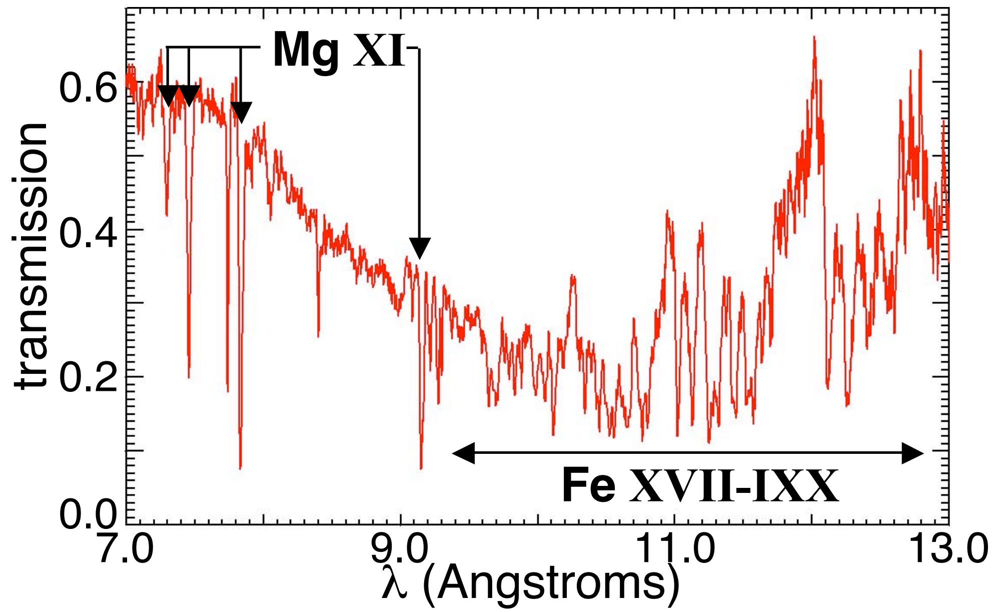
Z opacity experiments strengthen existing database and extend measurements beyond T ~ 150 eV



Fe + Mg transmission at
$T_e \sim 160$ eV, $n_e \sim 10^{22}$ cm^{-3}



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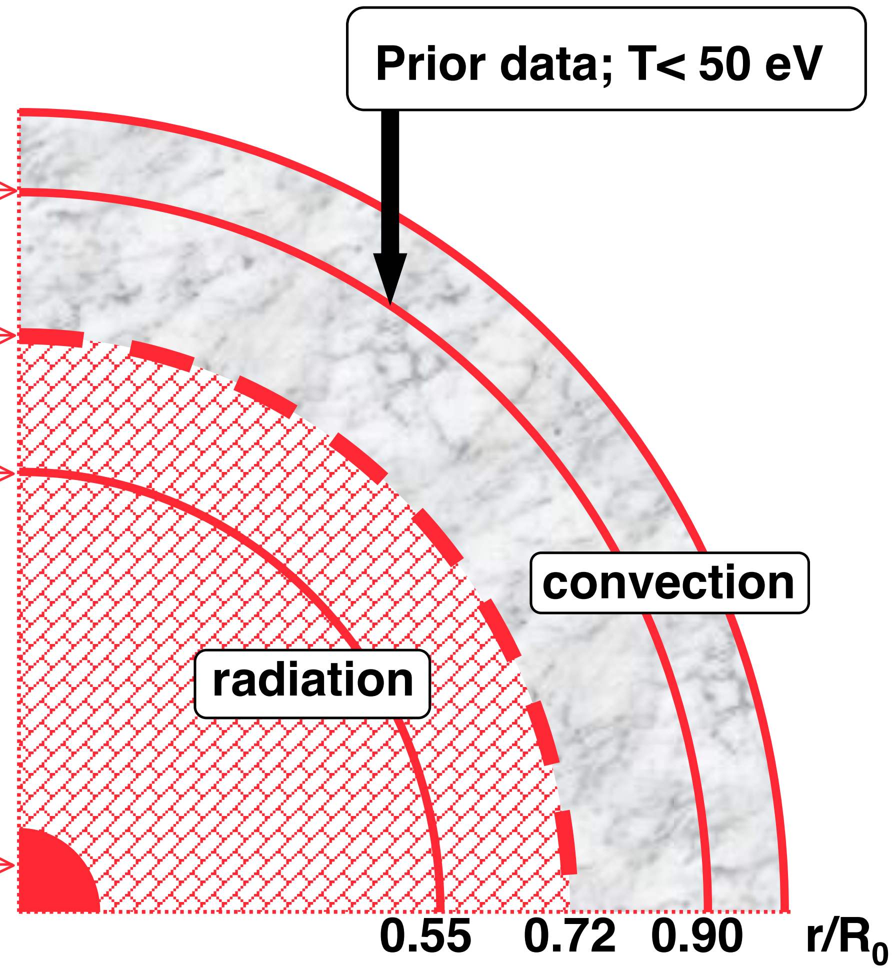
Laboratory opacity measurements at stellar interior conditions are not presently available

T(eV)	n_e (cm^{-3})	ρ (g/cc)
54	1×10^{22}	0.025
182	9×10^{22}	0.18
293	4×10^{23}	0.77
1360	6×10^{25}	157



Solar model : J.N. Bahcall et al, Rev. Mod. Phys. 54, 767 (1982)

Mid-Z and high-Z opacities are important for many HEDP physics problems

- ICF ablators, e.g., Cu-doped Be or Ge-doped CH at Te up to 300 eV
- Z-pinch radiation, e.g., tungsten at Te > 100 eV

- Published laboratory opacity measurements at T > 70 eV are unavailable (non-existant?)

Mid-Z elements pose a challenge for opacity calculations

- Charge state distribution (spectroscopic accuracy)
- What transitions must be included?
- What approximations for configuration and transition grouping?
- What line broadening?

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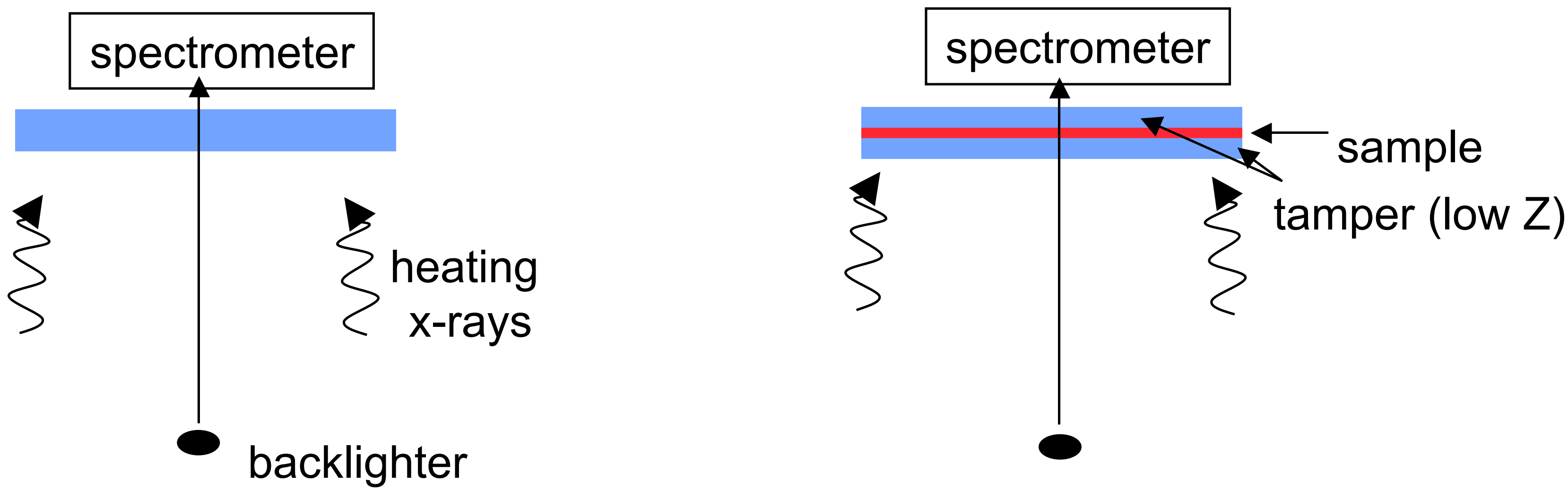
Anatomy of an opacity experiment



Comparison of unattenuated and attenuated spectra determines transmission
T = exp –{μρx}

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Desirable features of an opacity experiment

- Sample spatial uniformity (thin, large lateral size, thick tamper)
- Minimal temporal variations during probe time (backlight short compared to heating x-ray variation)
- Steady state (long duration heating x-rays)
- Temperature and density measurements (large wavelength range to enable simultaneous low Z and high Z measurements)

Characteristics of Z x-ray source can promote quality measurements

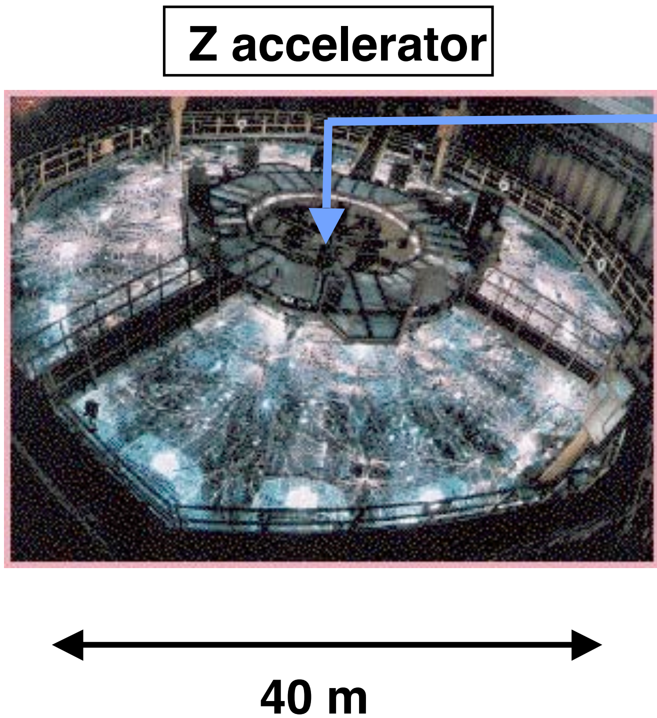
Possible experiment flaws can be evaluated from the scaling of transmission with sample thickness

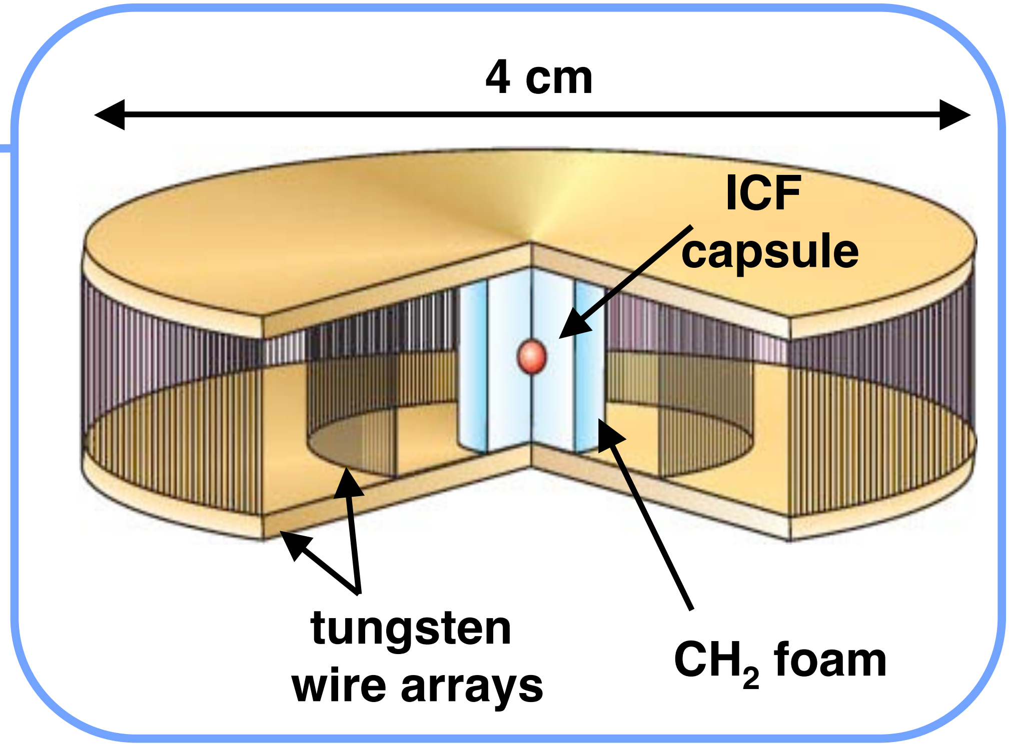
Potential experiment problems:

- Sample may not be cartoon-like (pinholes, columnar structure)
- Sample composition or areal density may not match specifications (oxidation, contamination)
- Sample self emission may alter apparent transmission
- Conversion of film density to film exposure may be inaccurate
- Background subtraction incorrect
- Crystal defects may introduce artificial spectral features or mask actual features
- Lines may saturate

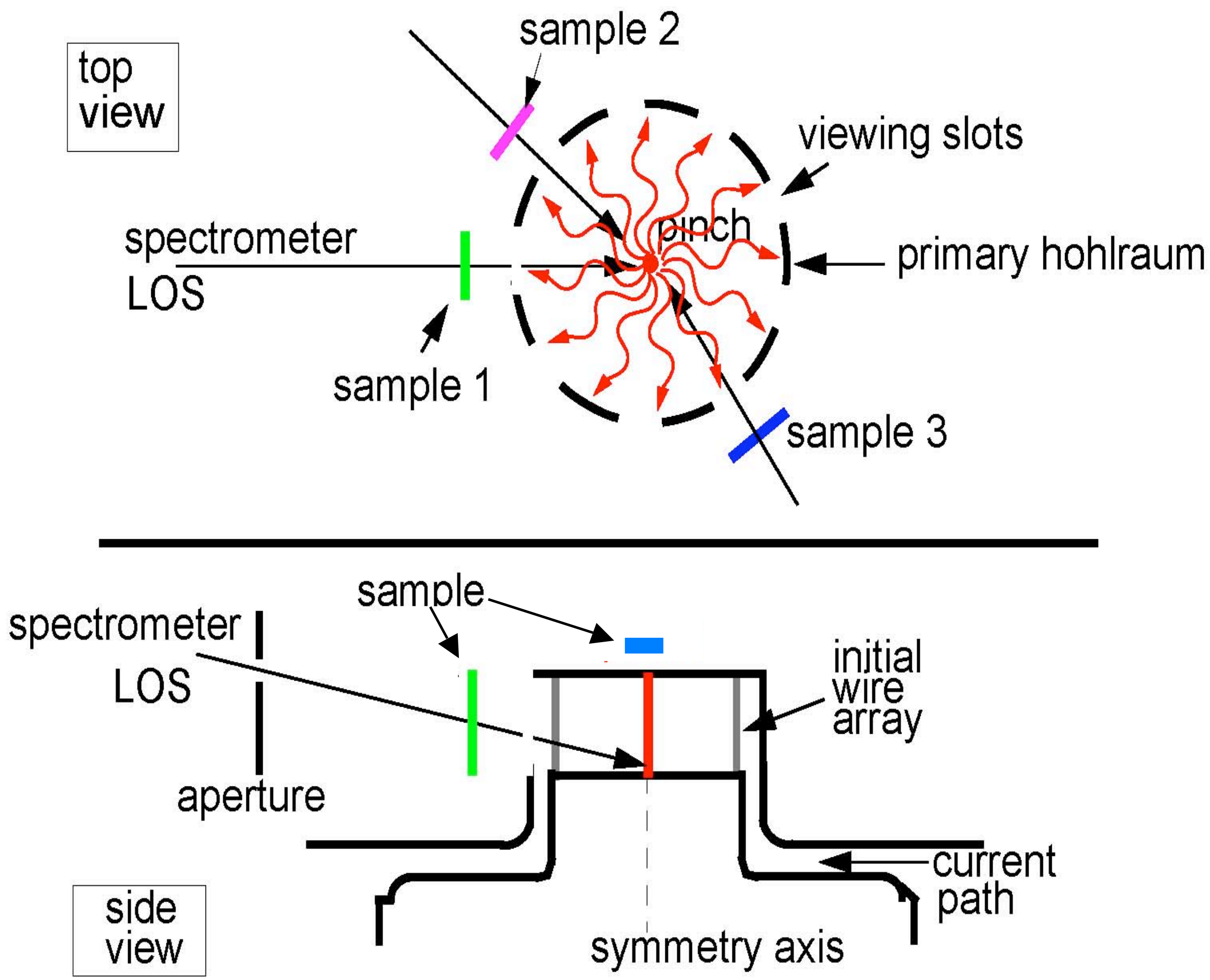
All of these problems cause transmission to deviate from expected scaling with thickness : $T_1 = T_2^{(x1/x2)}$

Opacity experiments can exploit the intense radiation provided by the Z accelerator





We have used two different opacity experiment configurations at Z



Each opacity experiment configuration offers advantages and disadvantages

Side-on:

- Multiple large samples exposed in a single experiment
- Many opportunities for ride alongs
- Temperature limited to ~ 50 eV or less

End-on:

- Single sample exposed in each experiment
- Relatively rare opportunities for ride alongs
- Temperatures above ~ 150 eV can be reached

Other configurations are feasible, but not yet demonstrated on Z

- External hohlraum (Springer et al., JQSRT 58, 927 (1997))
- Interior of dynamic hohlraum (Bailey et al, 2005)

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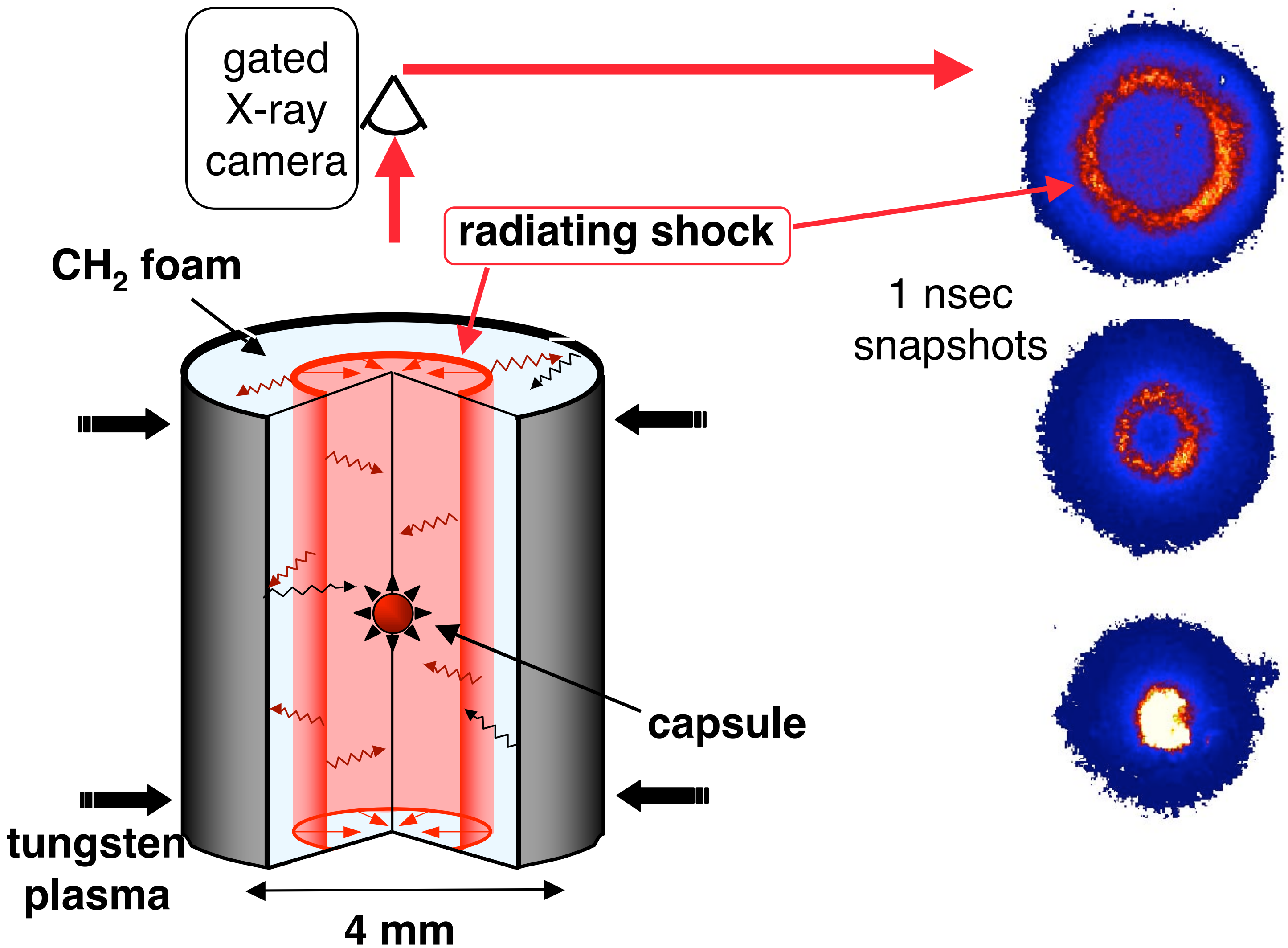
Dynamic hohlraum radiation source is created by accelerating a tungsten plasma onto a low Z foam



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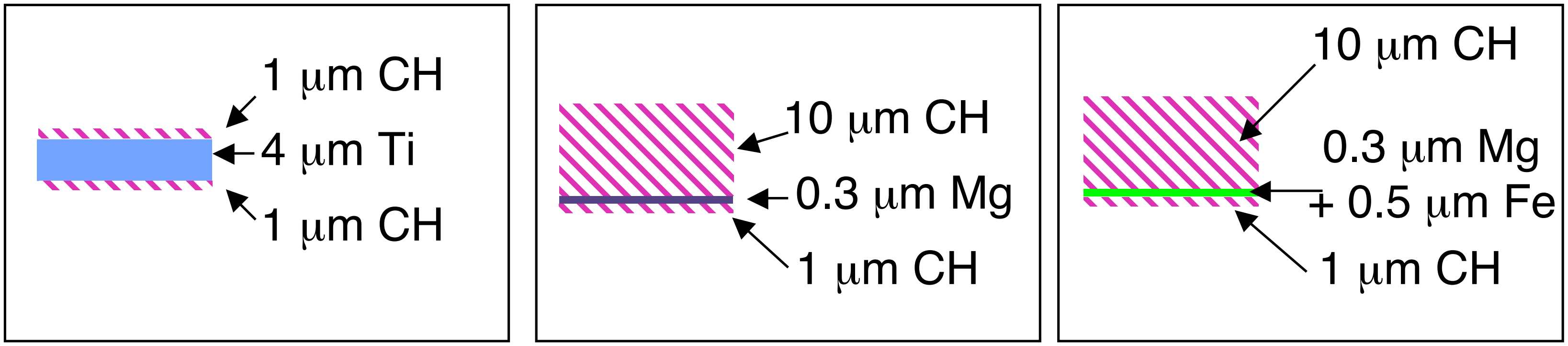
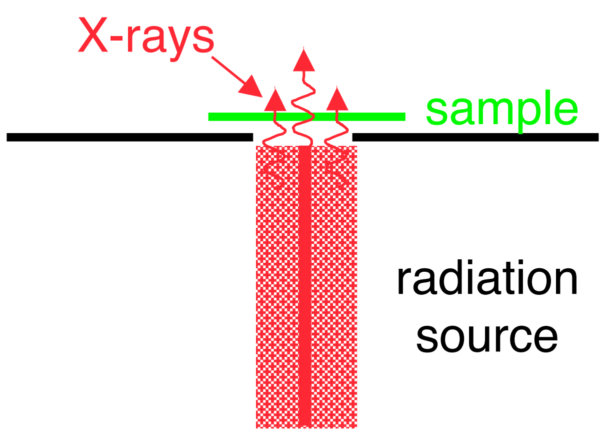
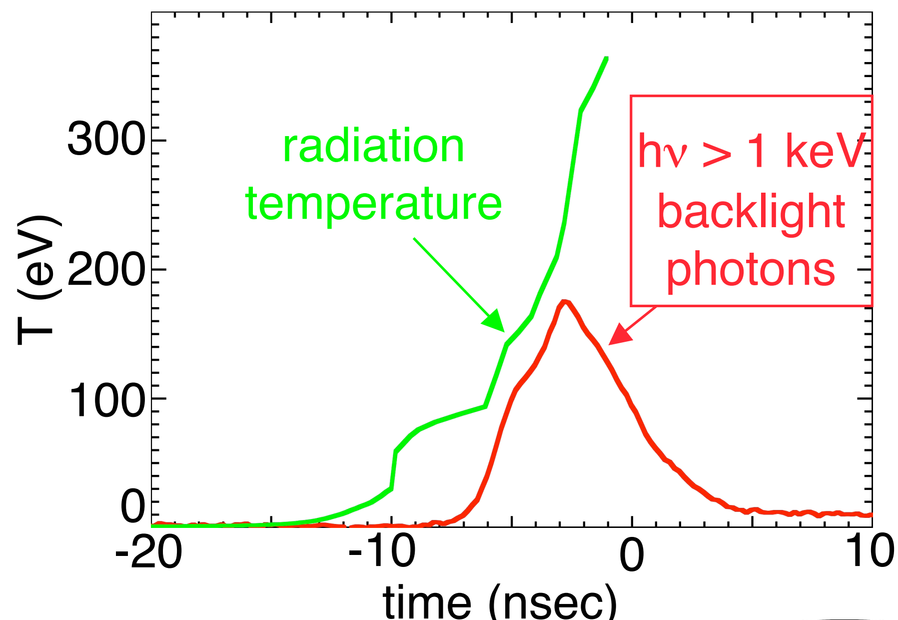
The radiation source heats and backlights the sample







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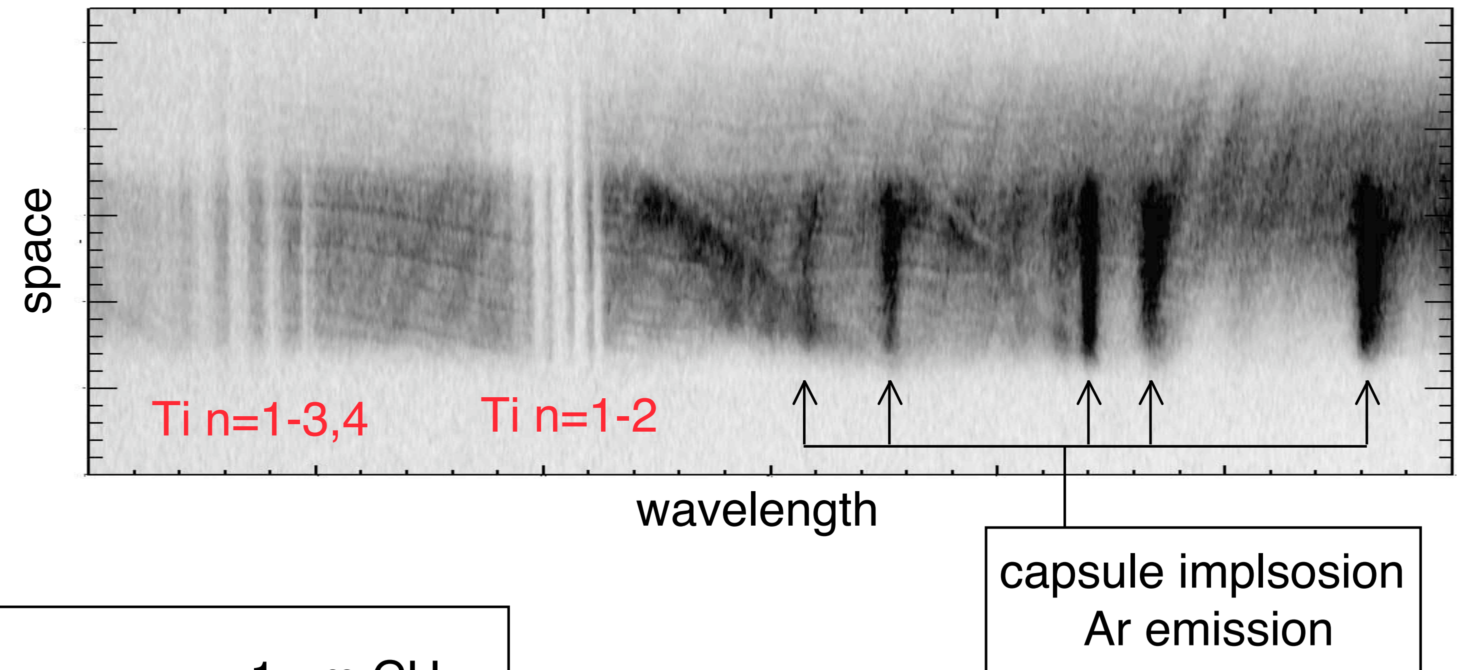
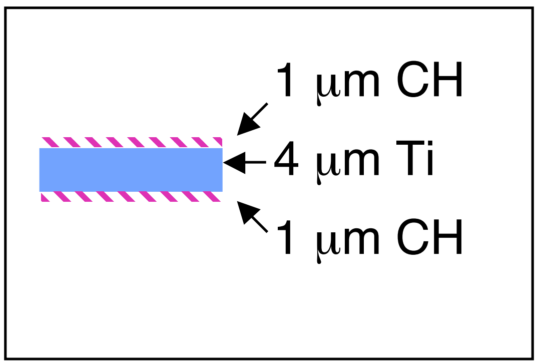
Opacity measurements were strongly suggested by Ti symmetry foil absorption spectra

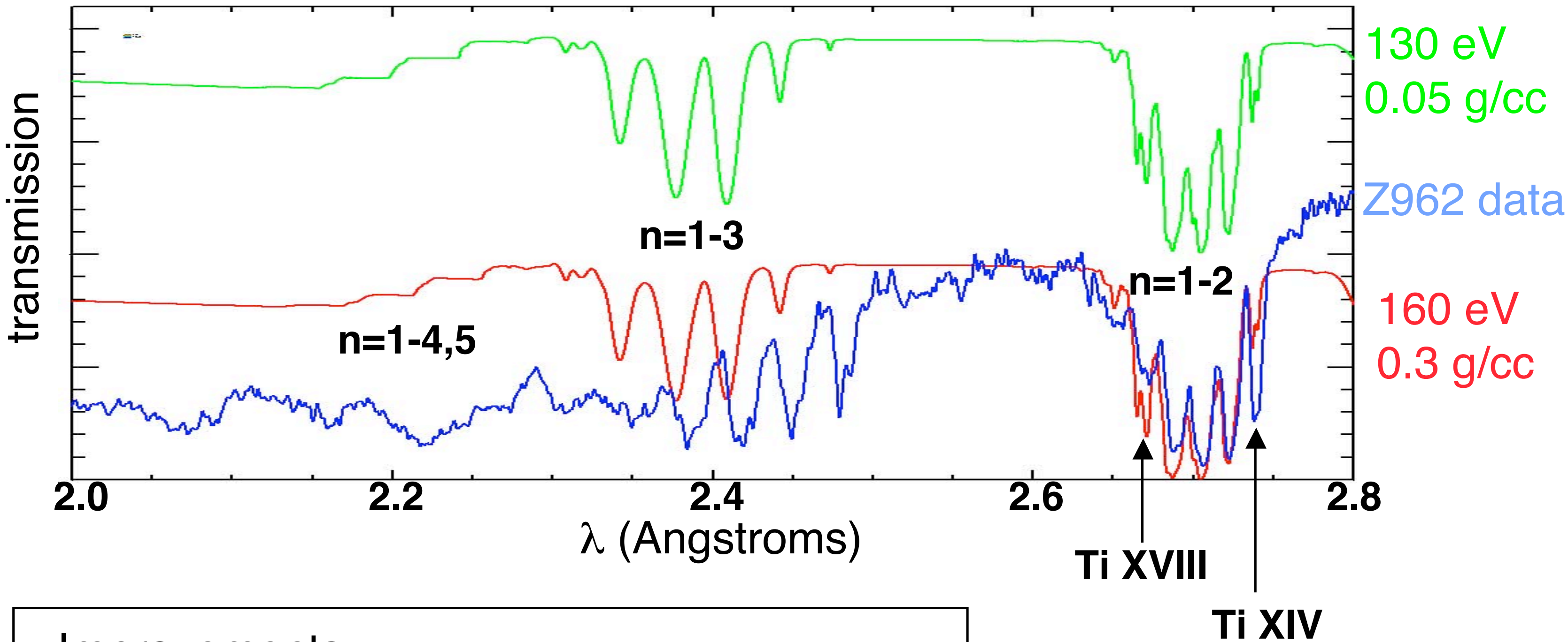




<u>This demonstrates:</u>

- Foils reach interesting conditions
- Self backlight source is very bright

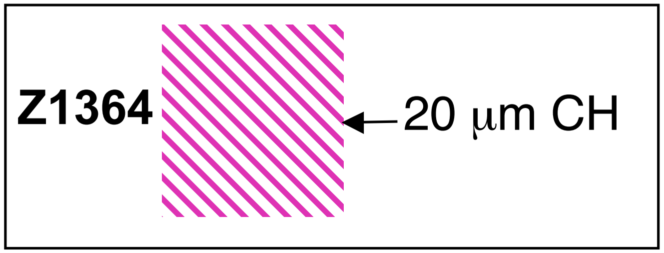
Ti absorption spectra are a rich opportunity for atomic physics, despite lack of optimization

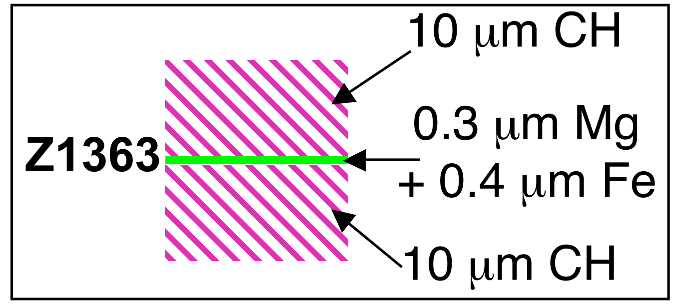


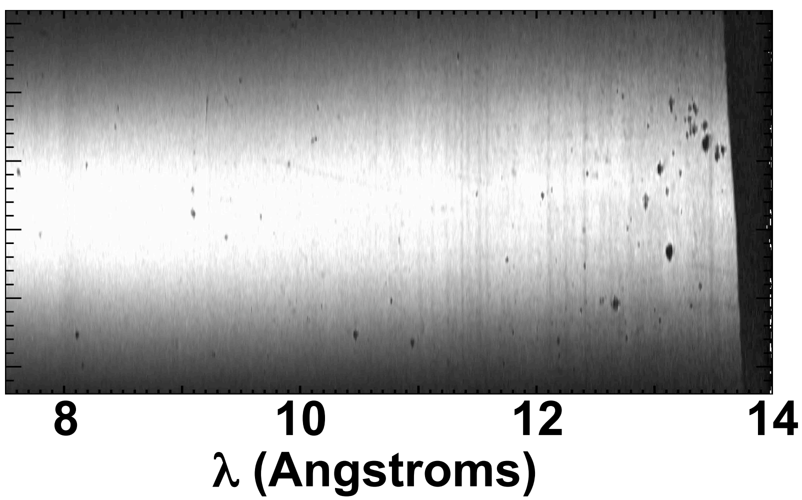
Improvements:

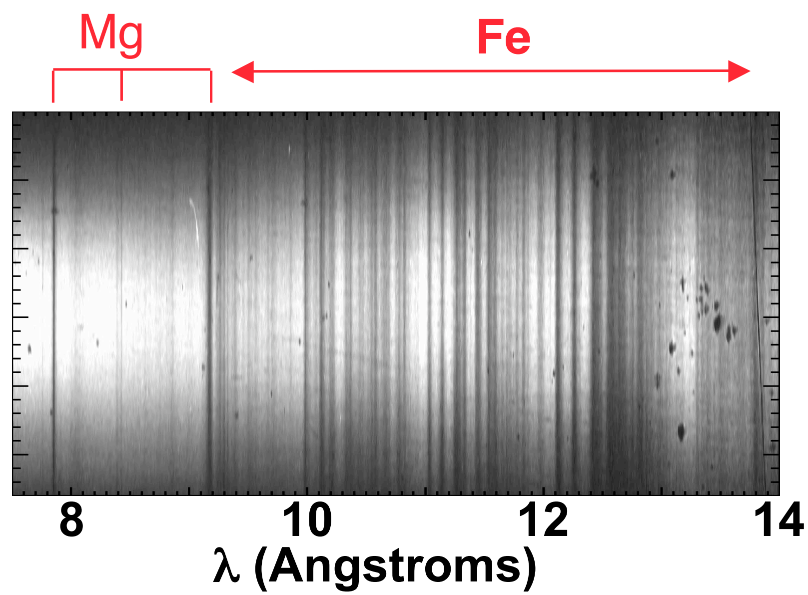
- Mixtures to obtain T, r diagnosis
- Reduced thickness to improve uniformity
- Better crystal quality

L-shell Fe absorption features have been successfully recorded



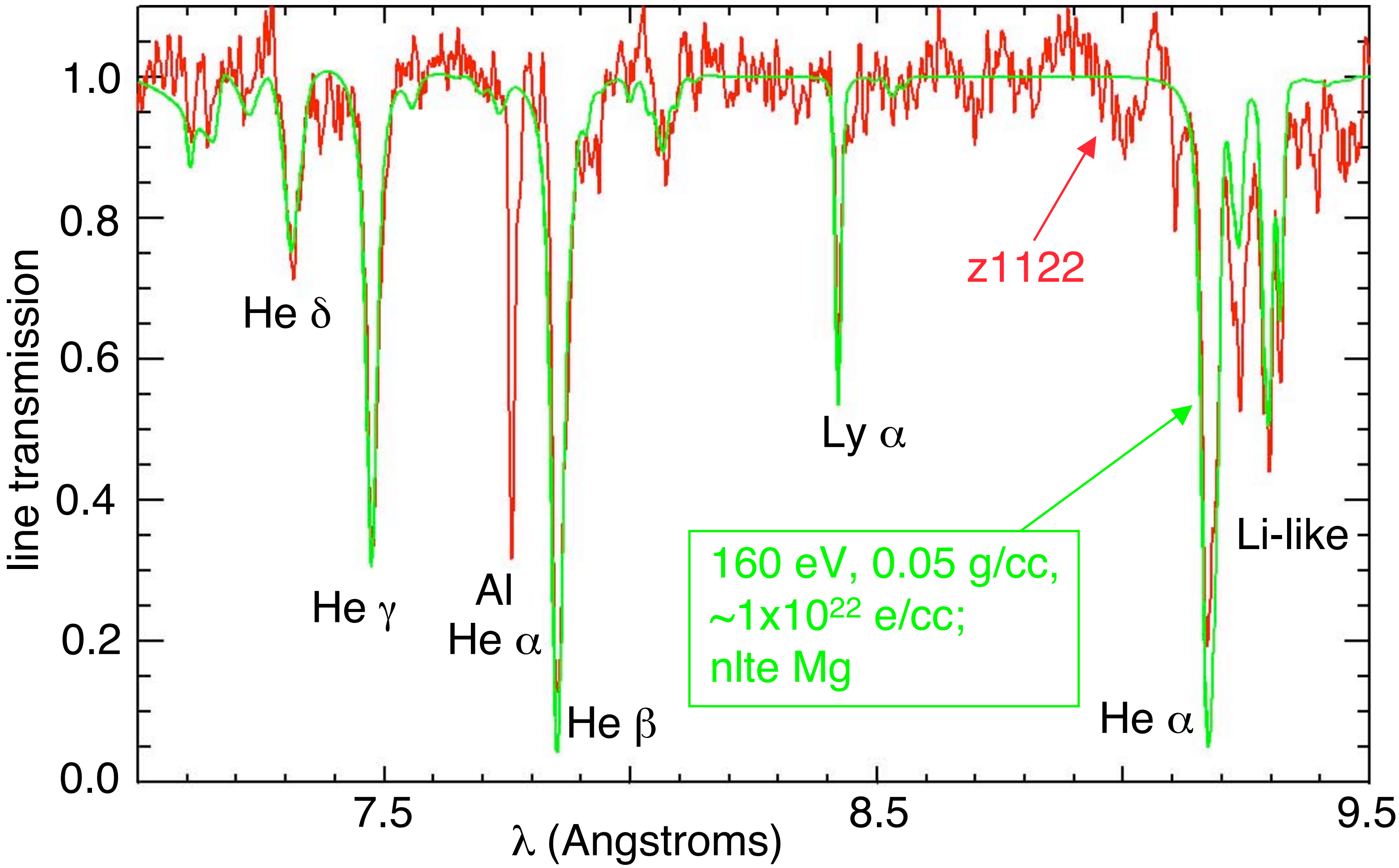




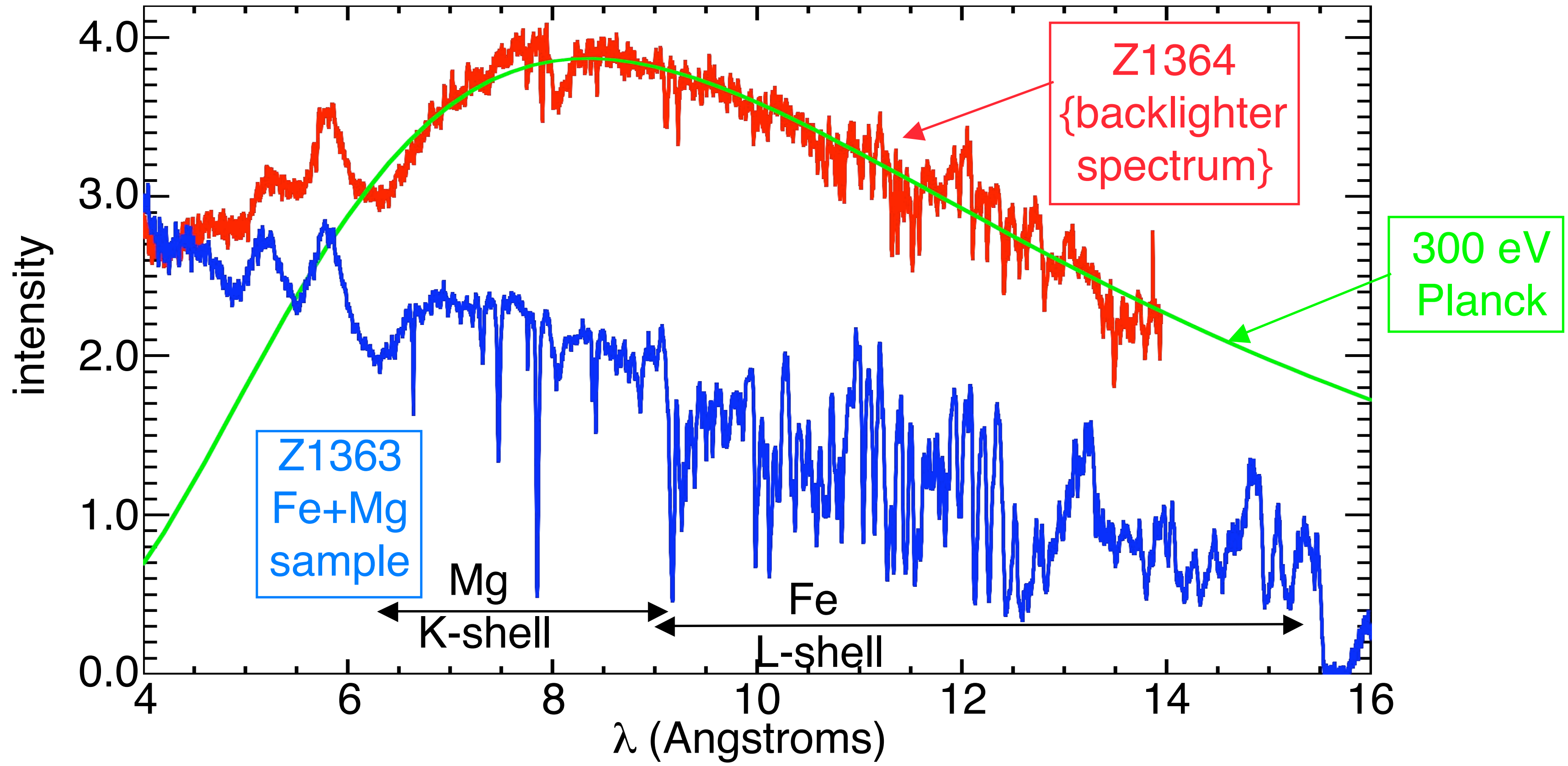


One pair of Z experiments determines the Fe + Mg transmission

The sample conditions are diagnosed from Mg absorption spectra



Experiments with and without Fe enable determination of the Fe transmission



- The difference between z1363 &z1364 is the Fe+Mg transmission
- Assuming shot to shot reproducibility

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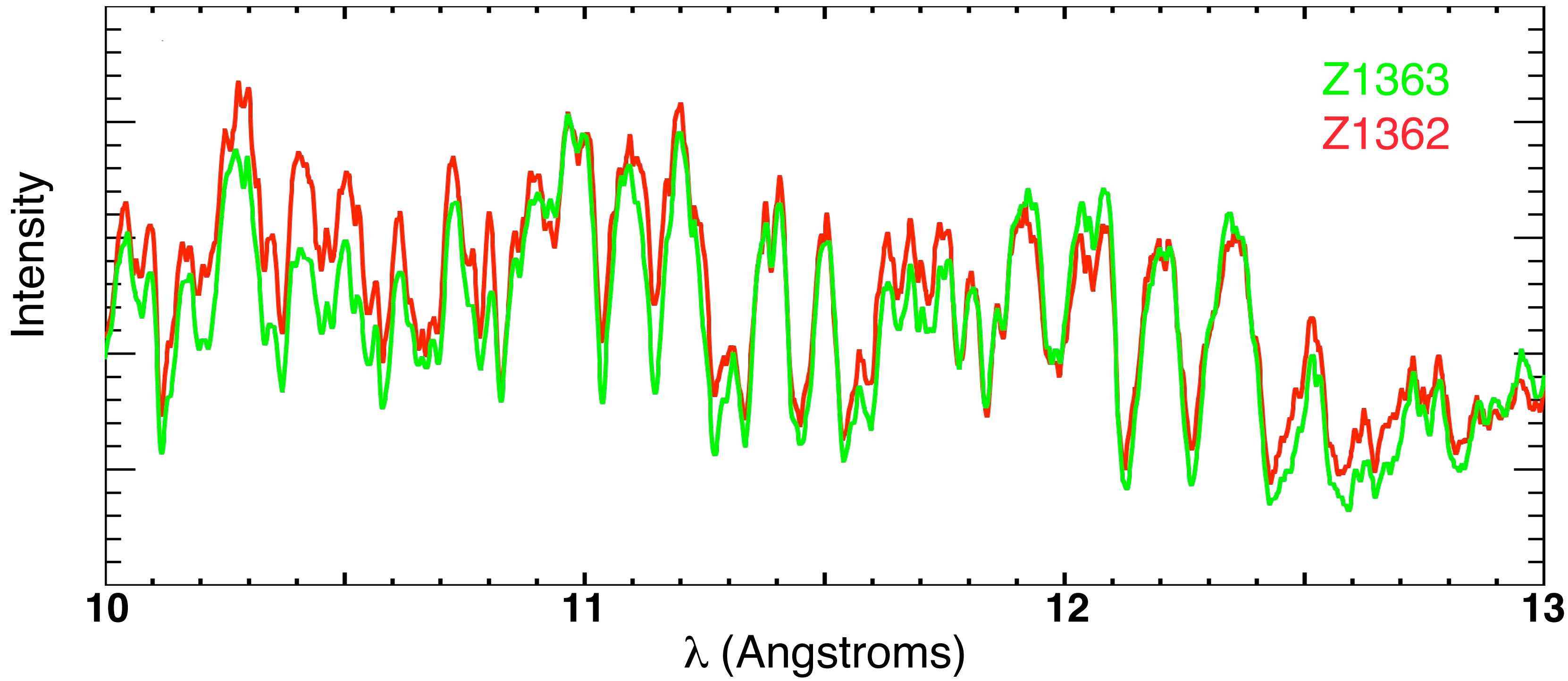
The shot to shot reproducibility is good, if conditions are carefully controlled



- Both experiments used 10 μm CH | 0.3 μm Mg + 0.4 μm Fe | 10 μm CH sample
- No scaling was applied for this comparison
- Reproducibility is approximately 10% or better over this wavelength range

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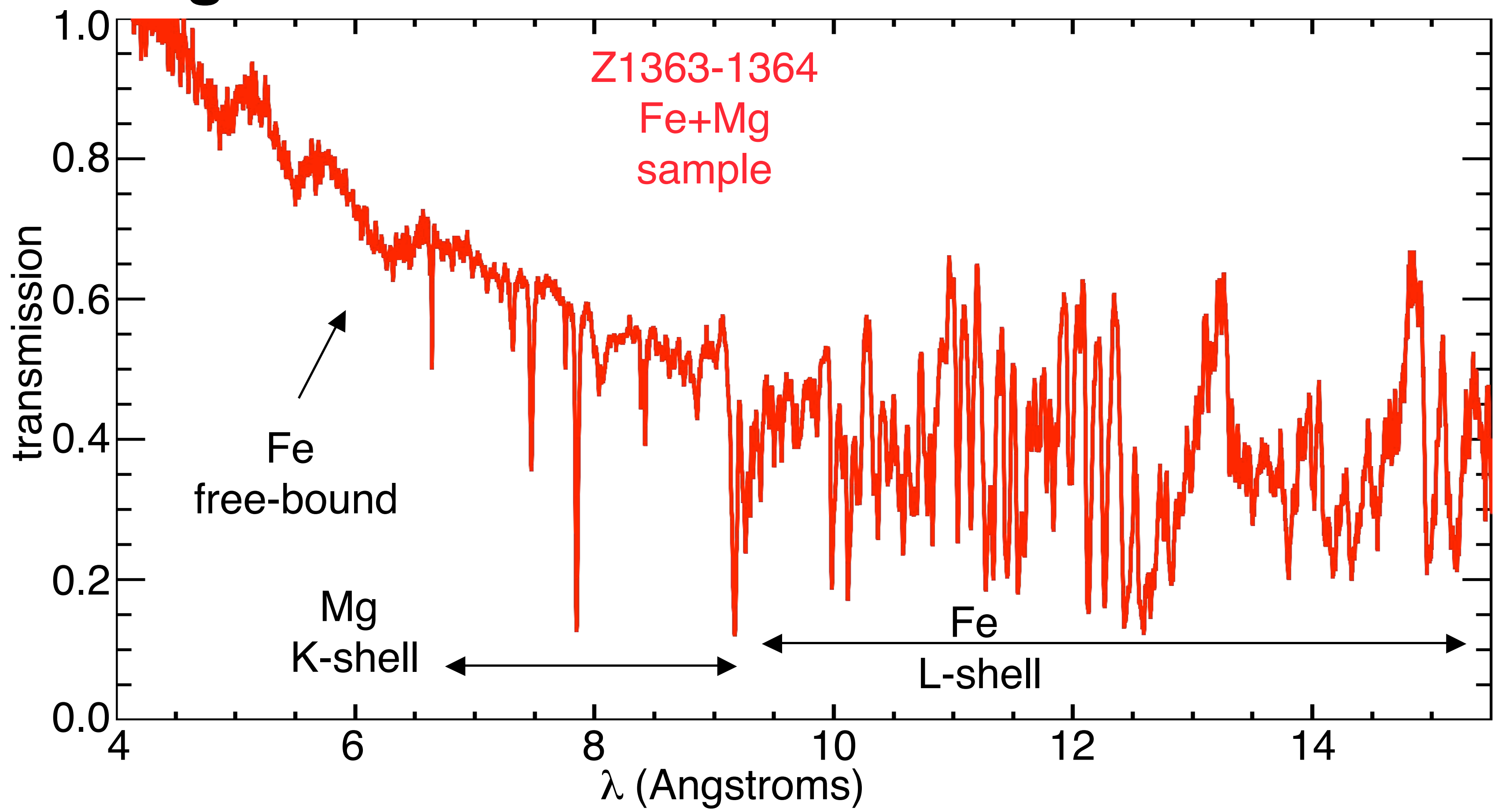
The dynamic hohlarum backlighter measures transmission over a very broad λ range



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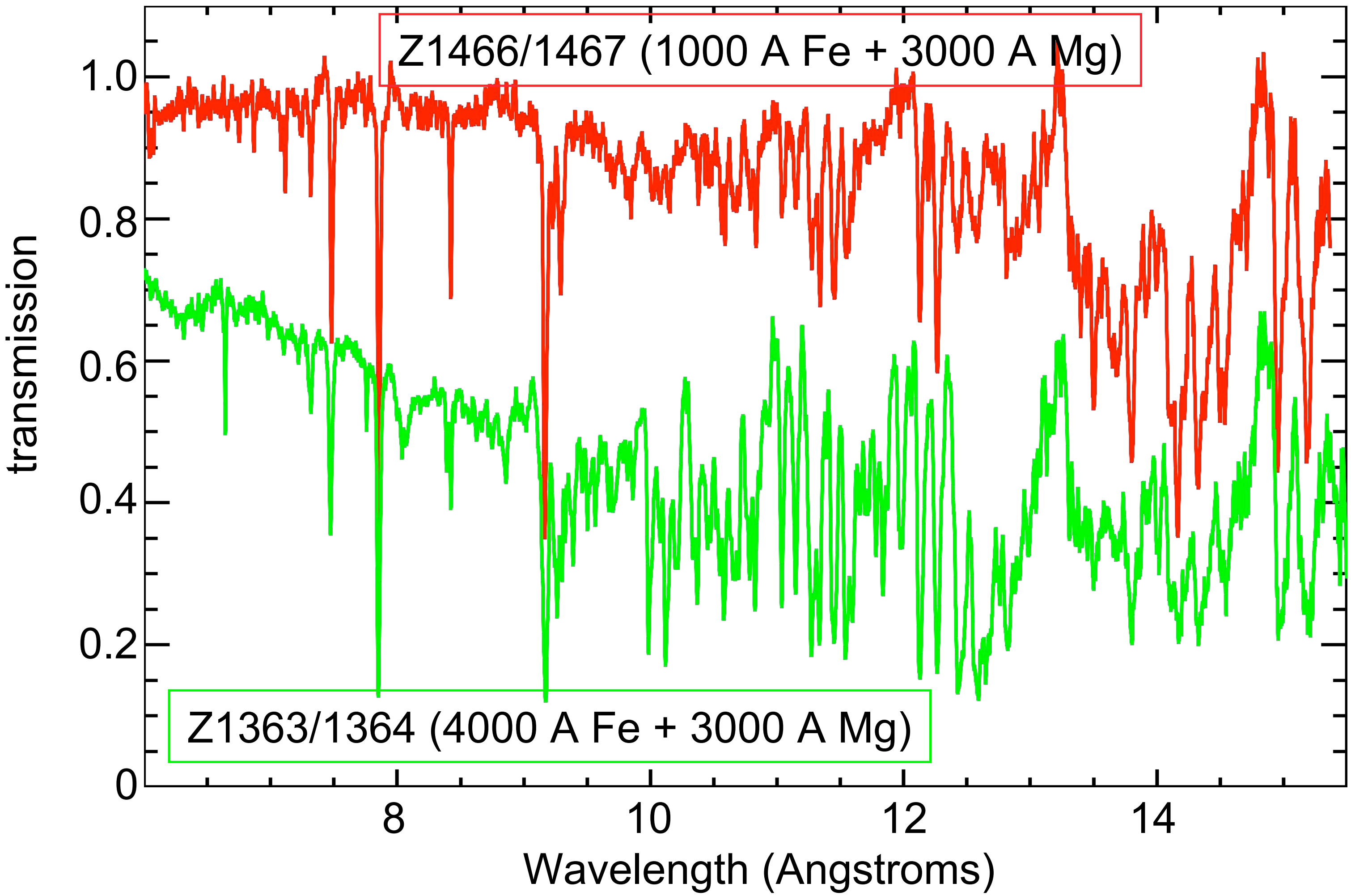
Transmission for two Fe thicknesses under similar T_e and n_e conditions has been measured



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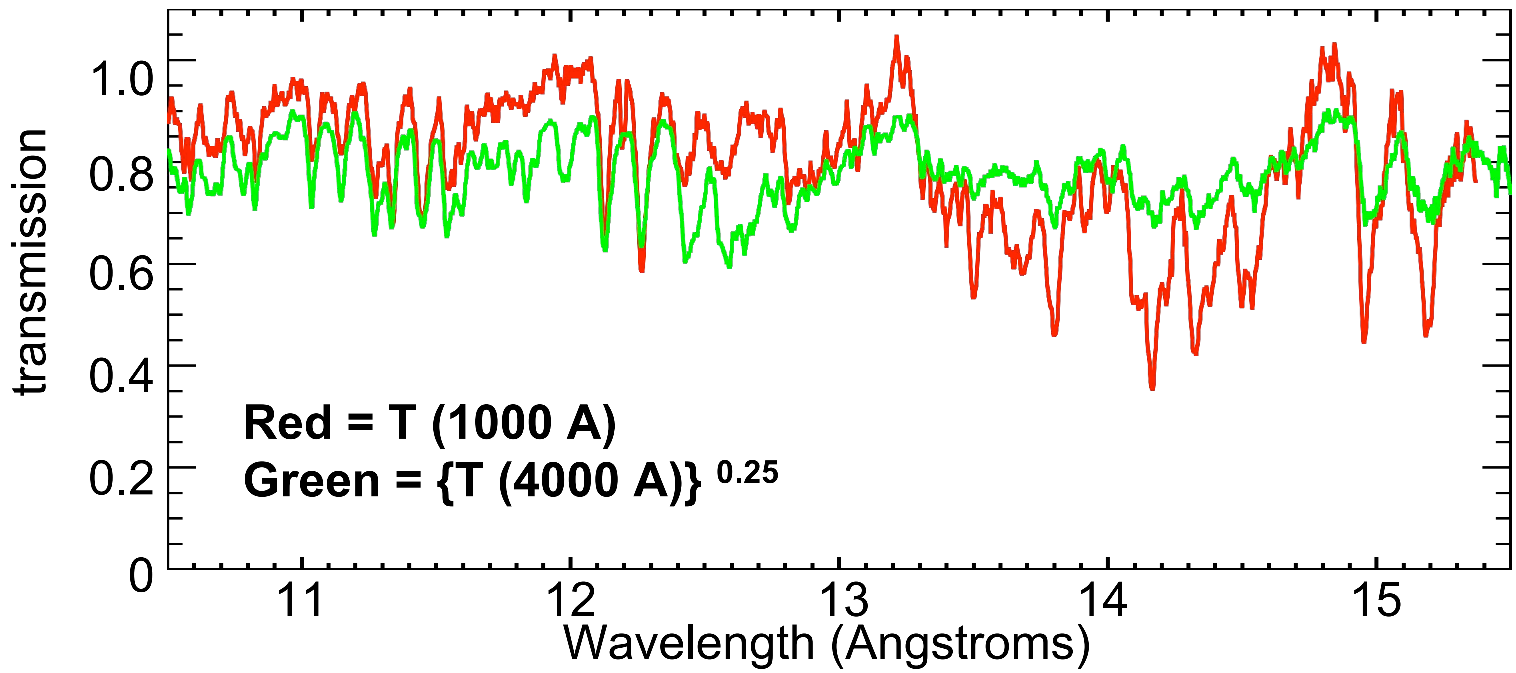
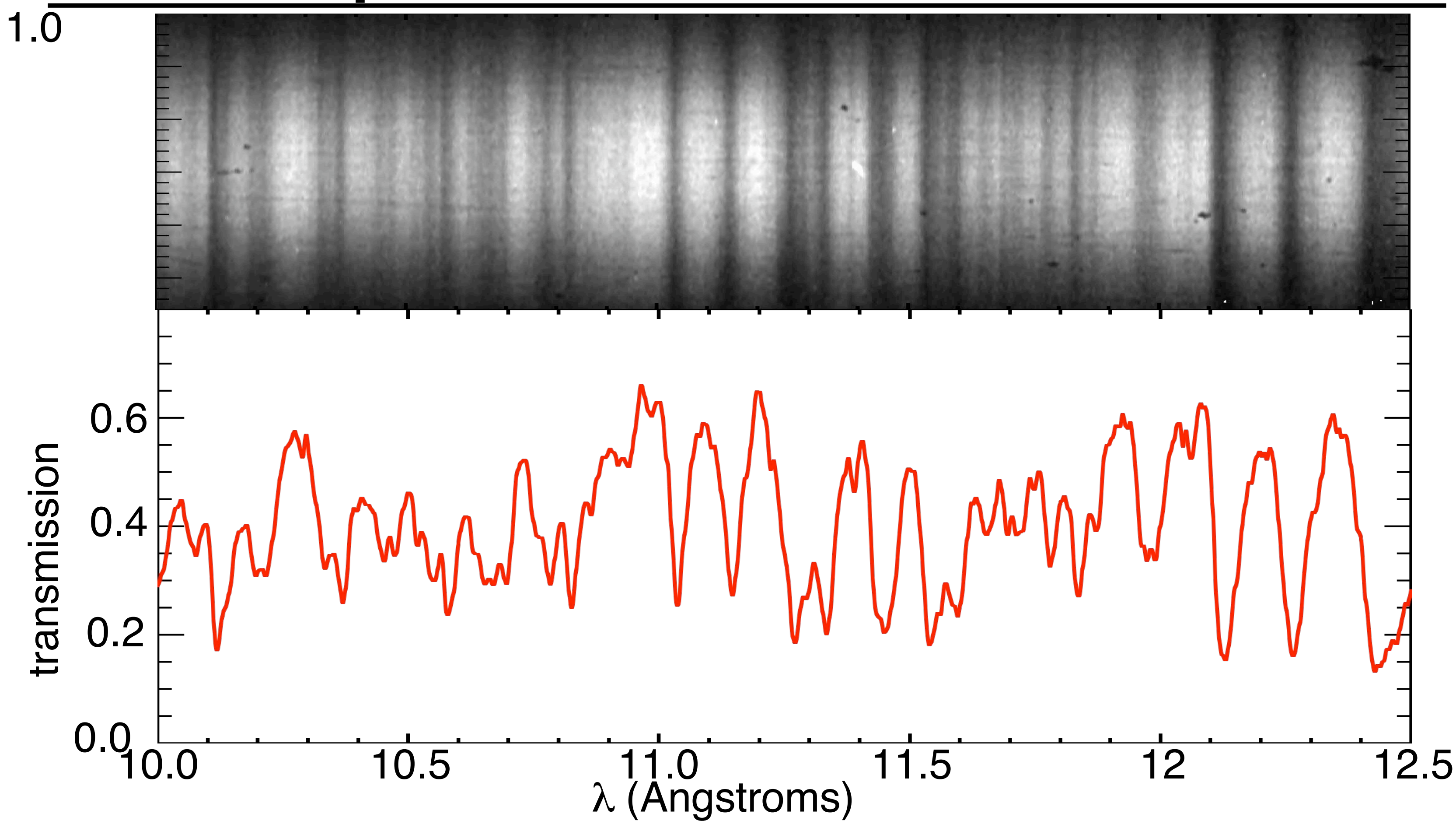
The transmission data scales with the thickness approximately as expected



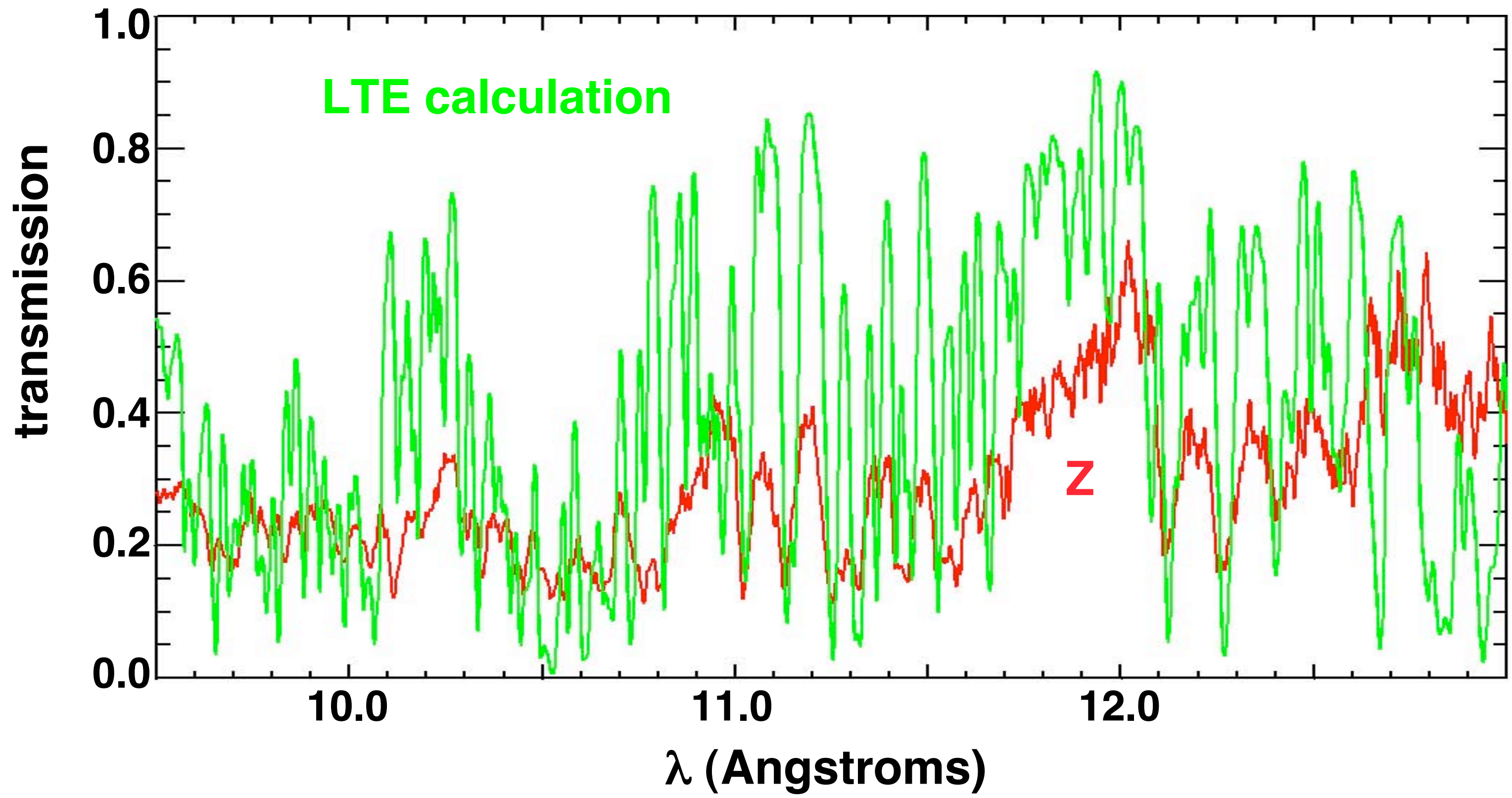
- Significant portions of the spectrum scales with $\{ T \}^{x}$, with x=thickness
- This supports method robustness - correct areal density, negligible self emission, correct film response, correct background subtraction
- Residual differences due to line saturation, possibly different Te, ne

The Fe L-shell spectrum exhibits a wealth of line absorption features



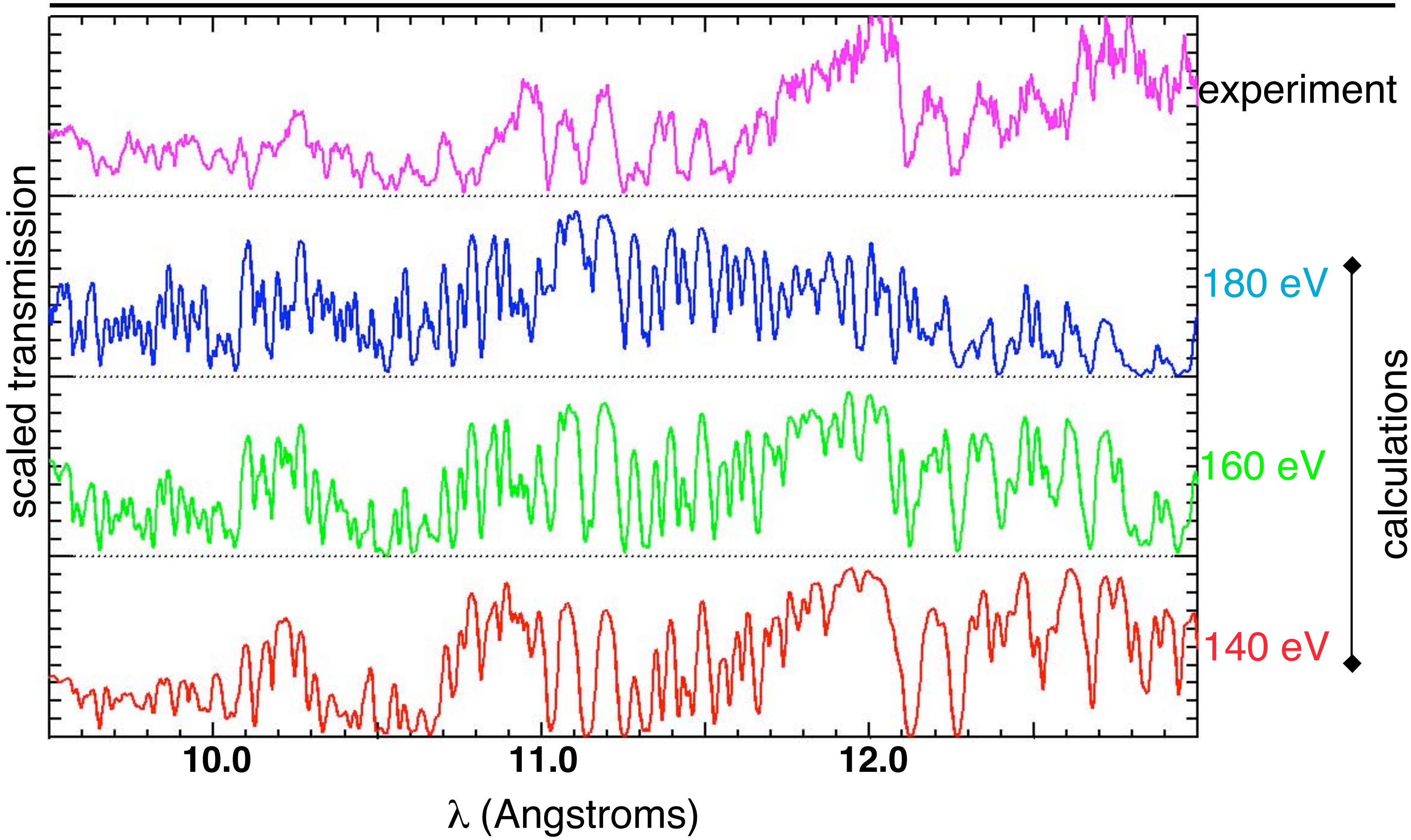
- **Reproducing these features is a difficult test for any opacity model**

PRISMSPECT calculations exhibit respectable agreement with Fe transmission

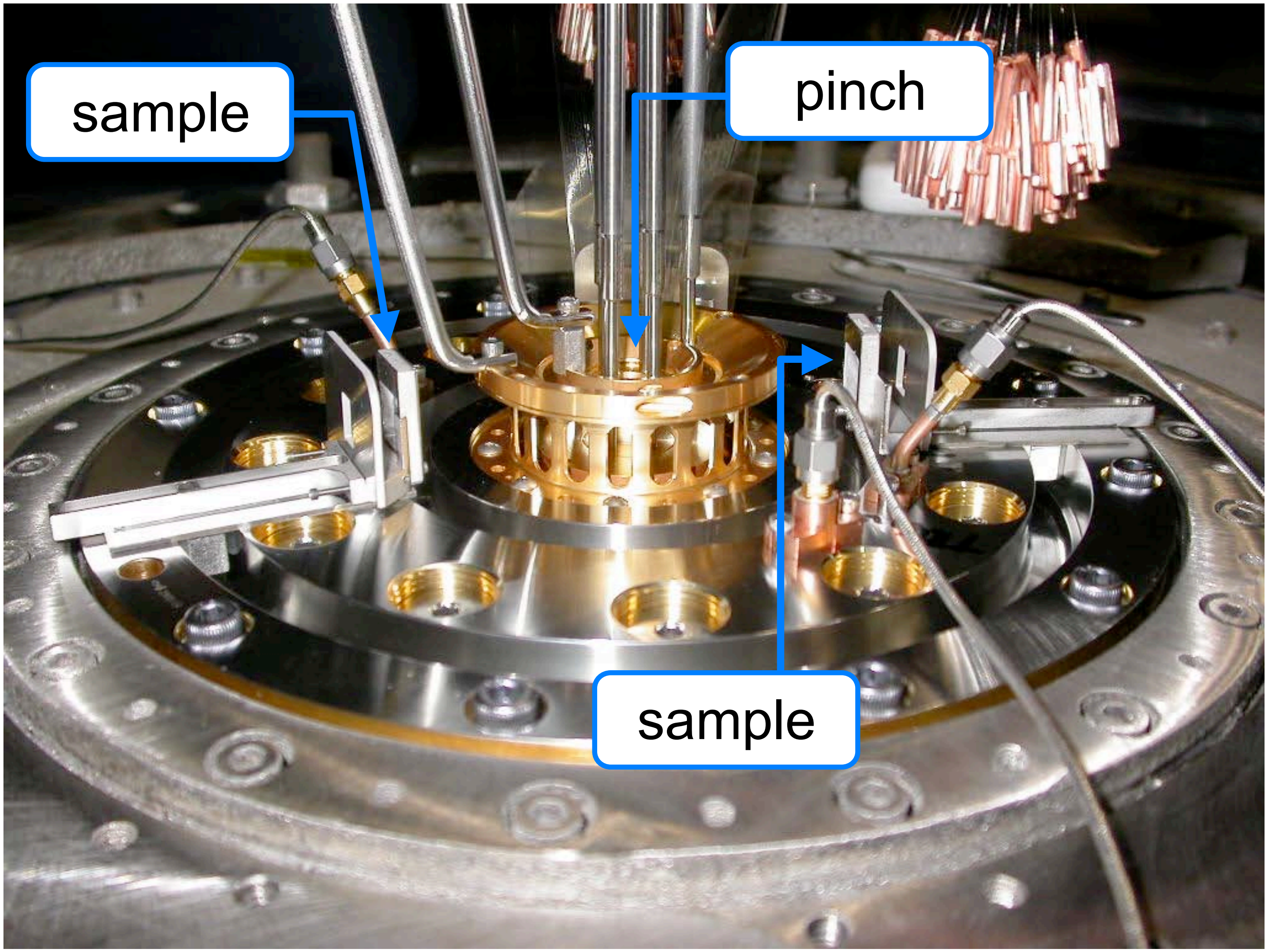


- The main features are well reproduced
- The calculated transmission has “windows” between the lines

The data enables tests of the calculated charge state distribution

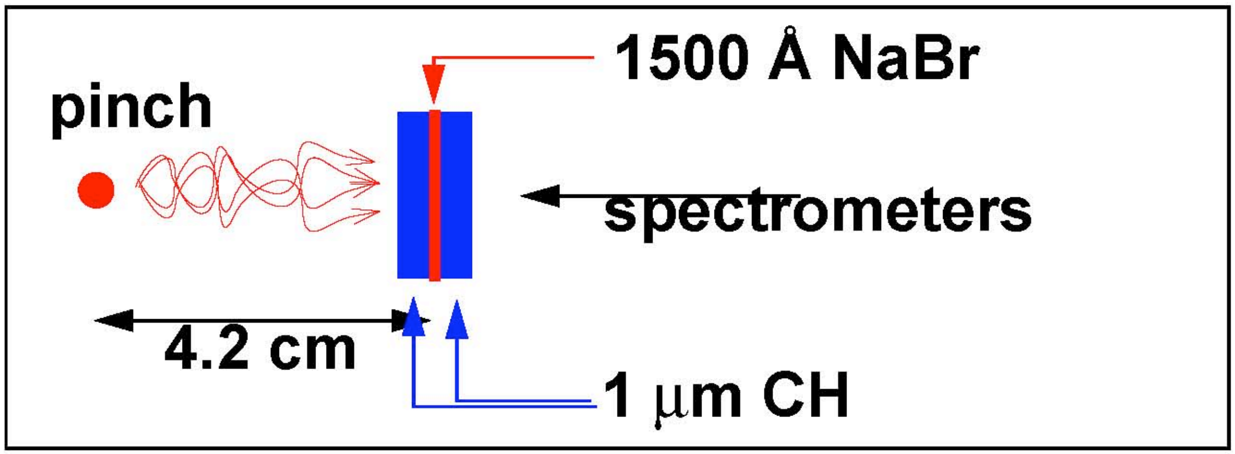


Side-on opacity experiments use samples placed ~ 5 cm from the pinch



The ability to measure complex opacities is being developed using open M-shell bromine.

<u>Goal for ride-alongs:</u>
Use *FREE* radiation to measure opacities at
~ 20-70 eV and ~10^{-3} - 10^{-2} g/cc



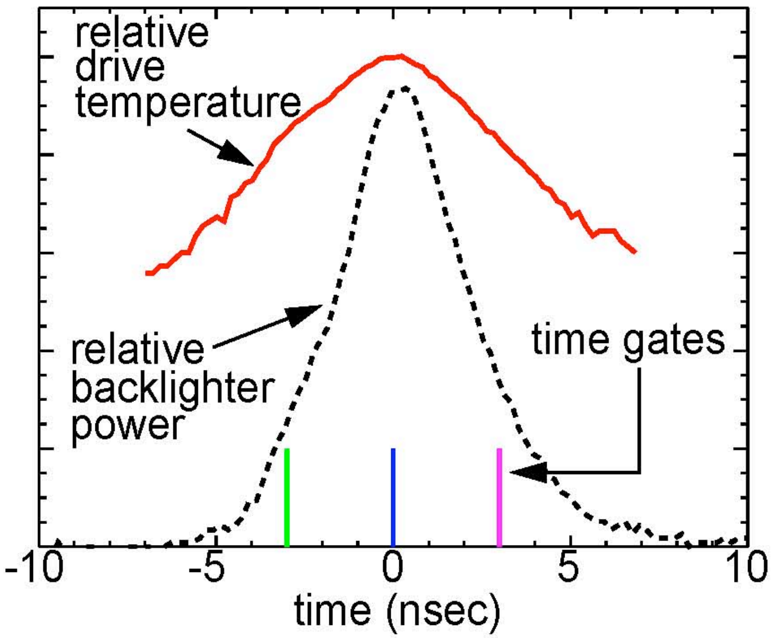
<u>Basic idea:</u>

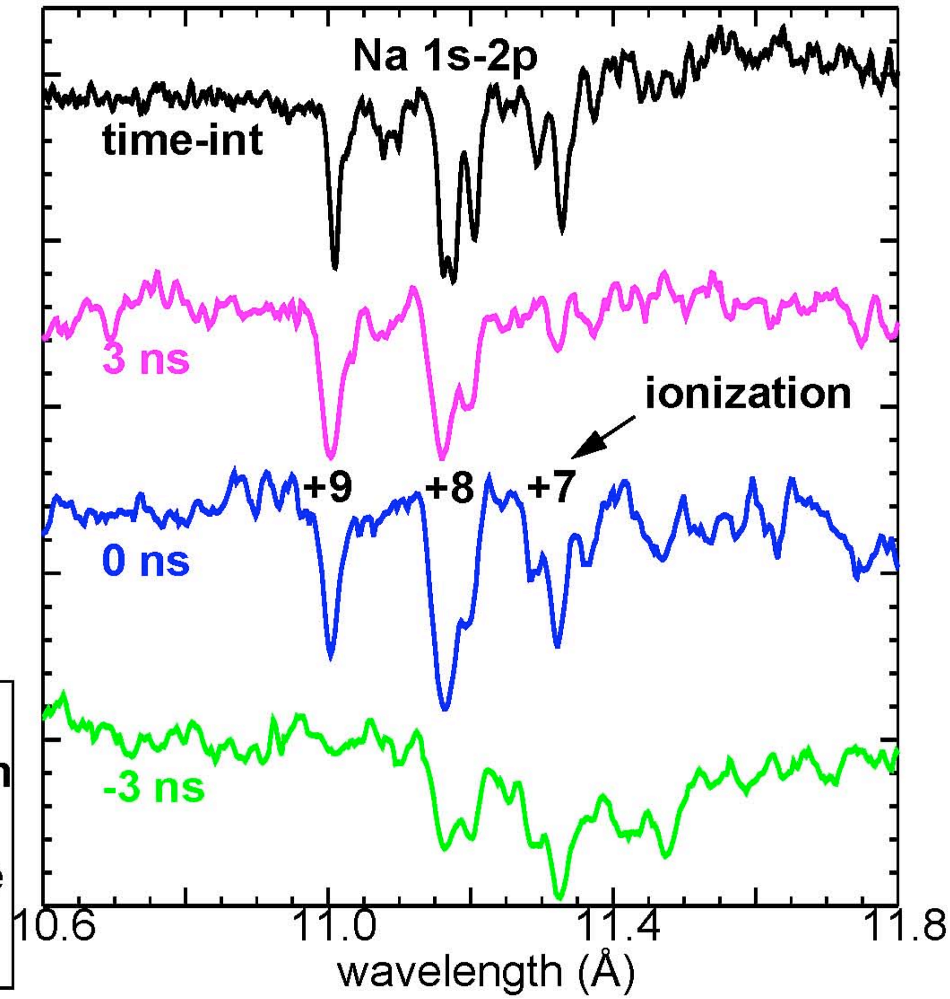
Pinch both heats and backlights sample

Na = thermometer; Br = test element

Develop method, then many elements can be measured

The drive temperature changes only by a modest amount over the z-pinch backlighter duration

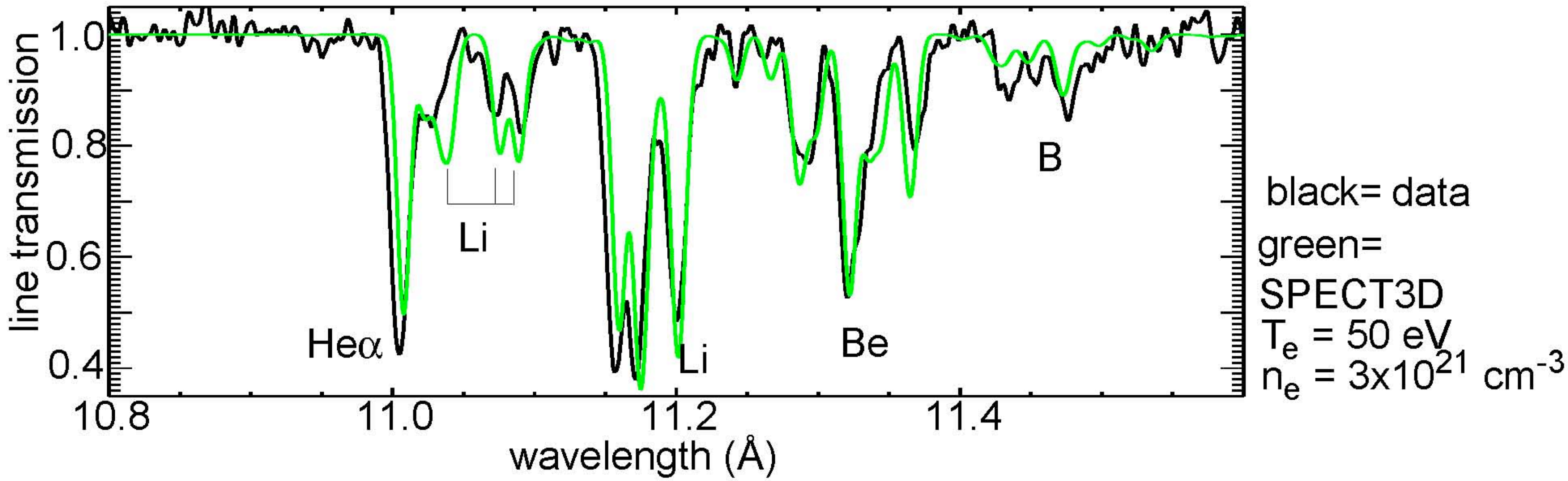


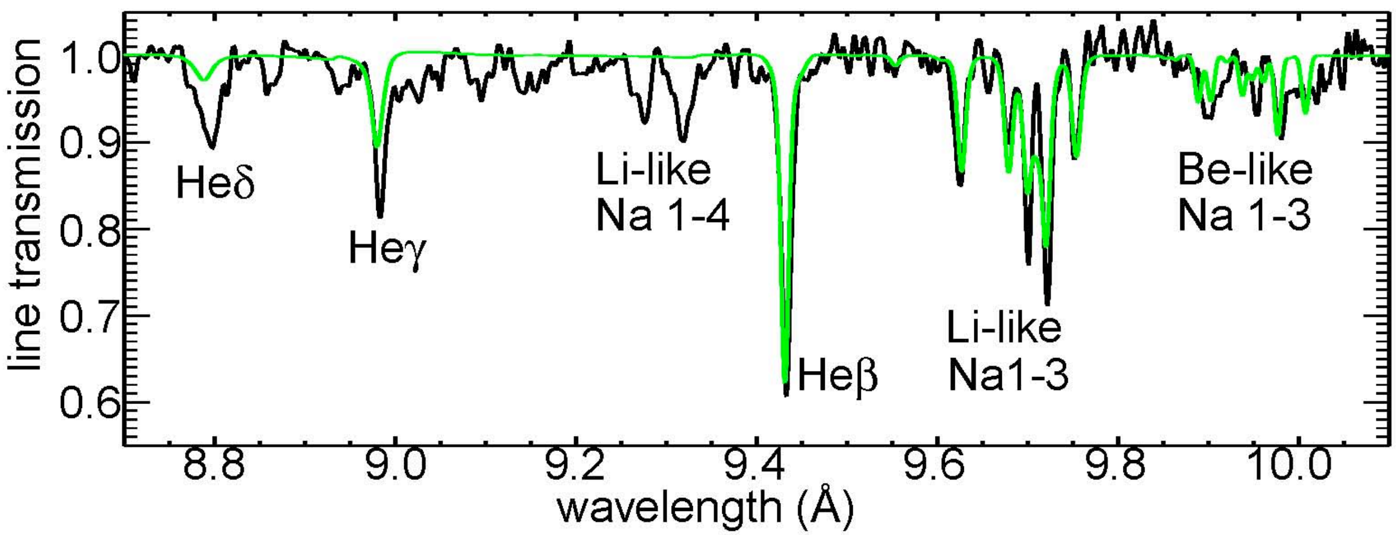


time-integrated spectrum ~
peak power time-resolved spectrum

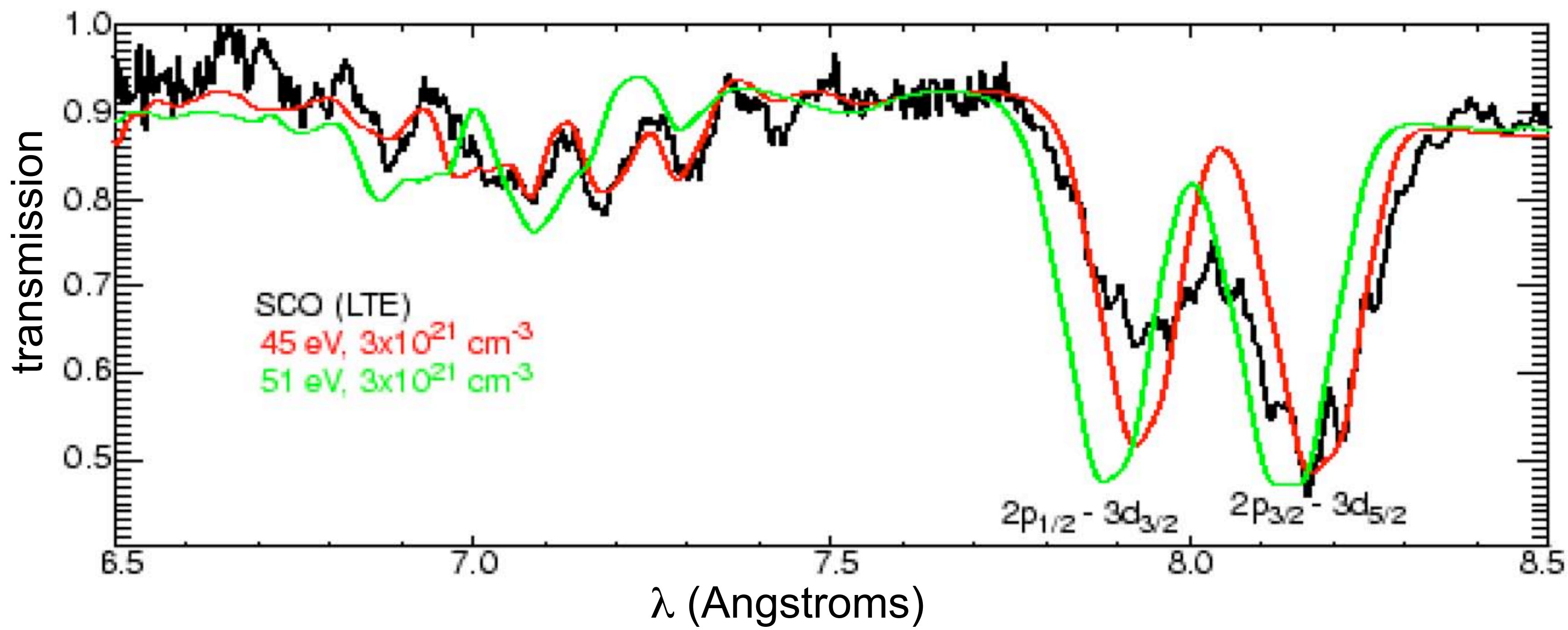
time-integrated spectrometers have
superior range and resolution

The temperature and density are diagnosed with roughly ± 10% and ± 30% uncertainties, respectively



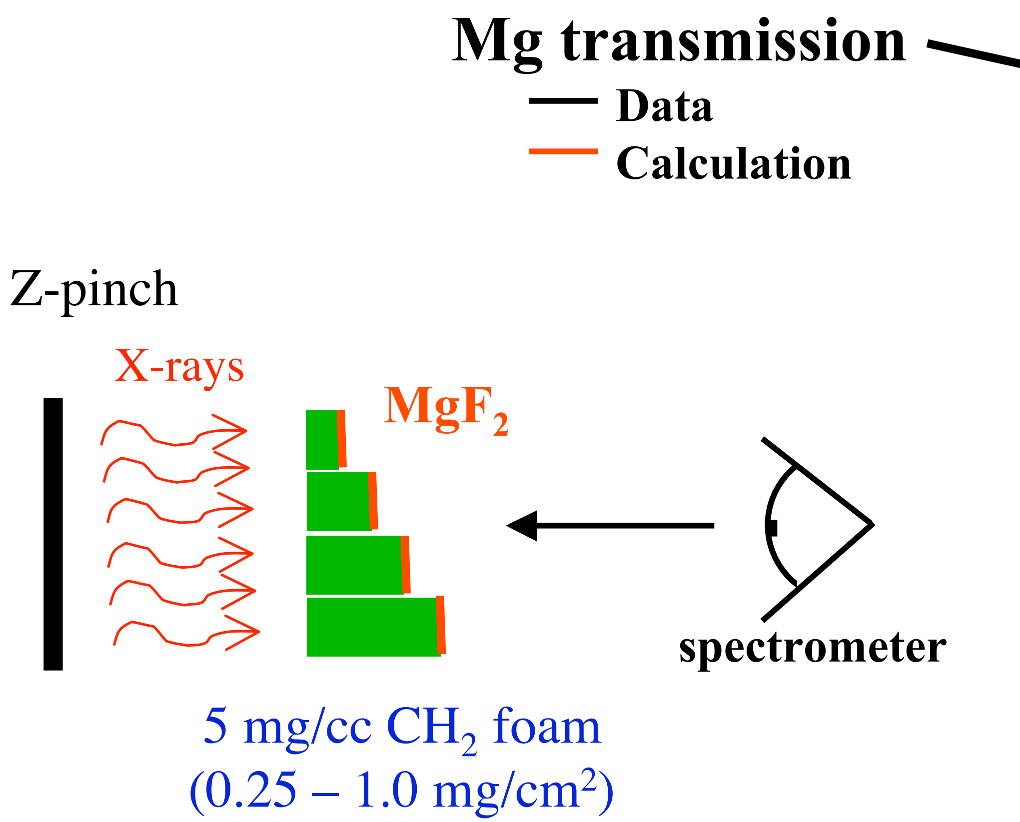


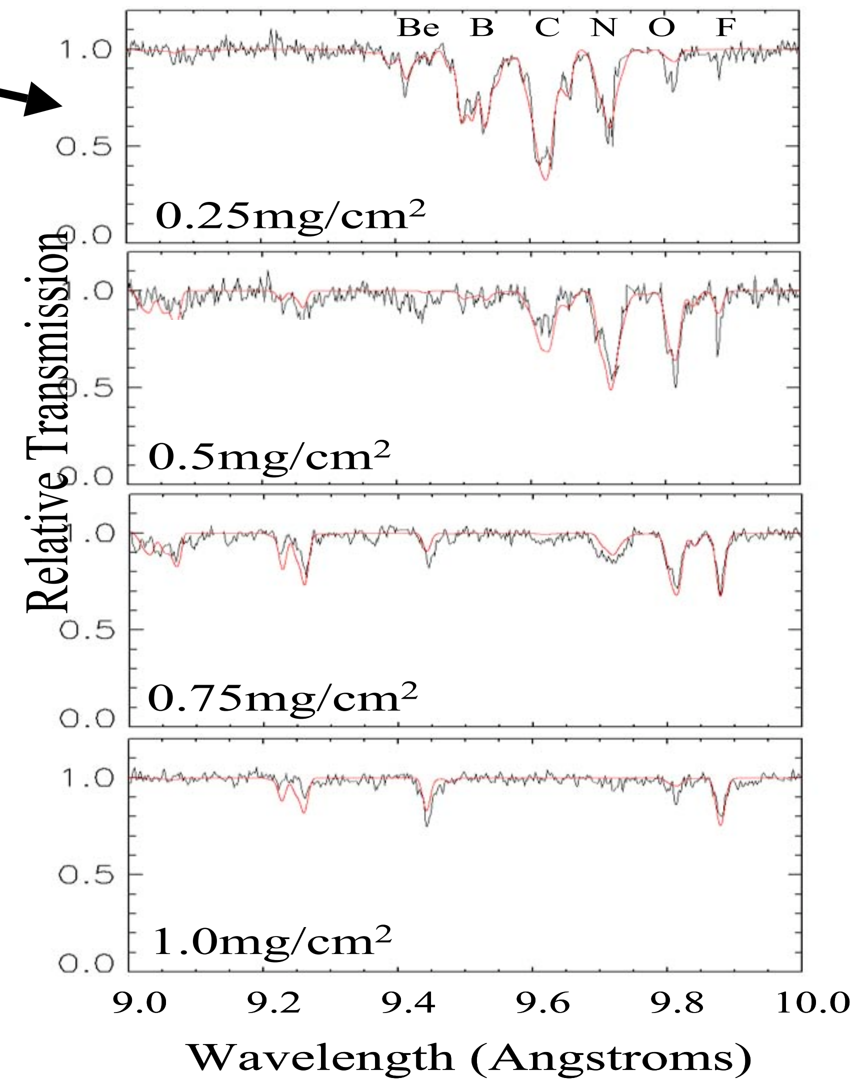
NaBr data can test opacity models



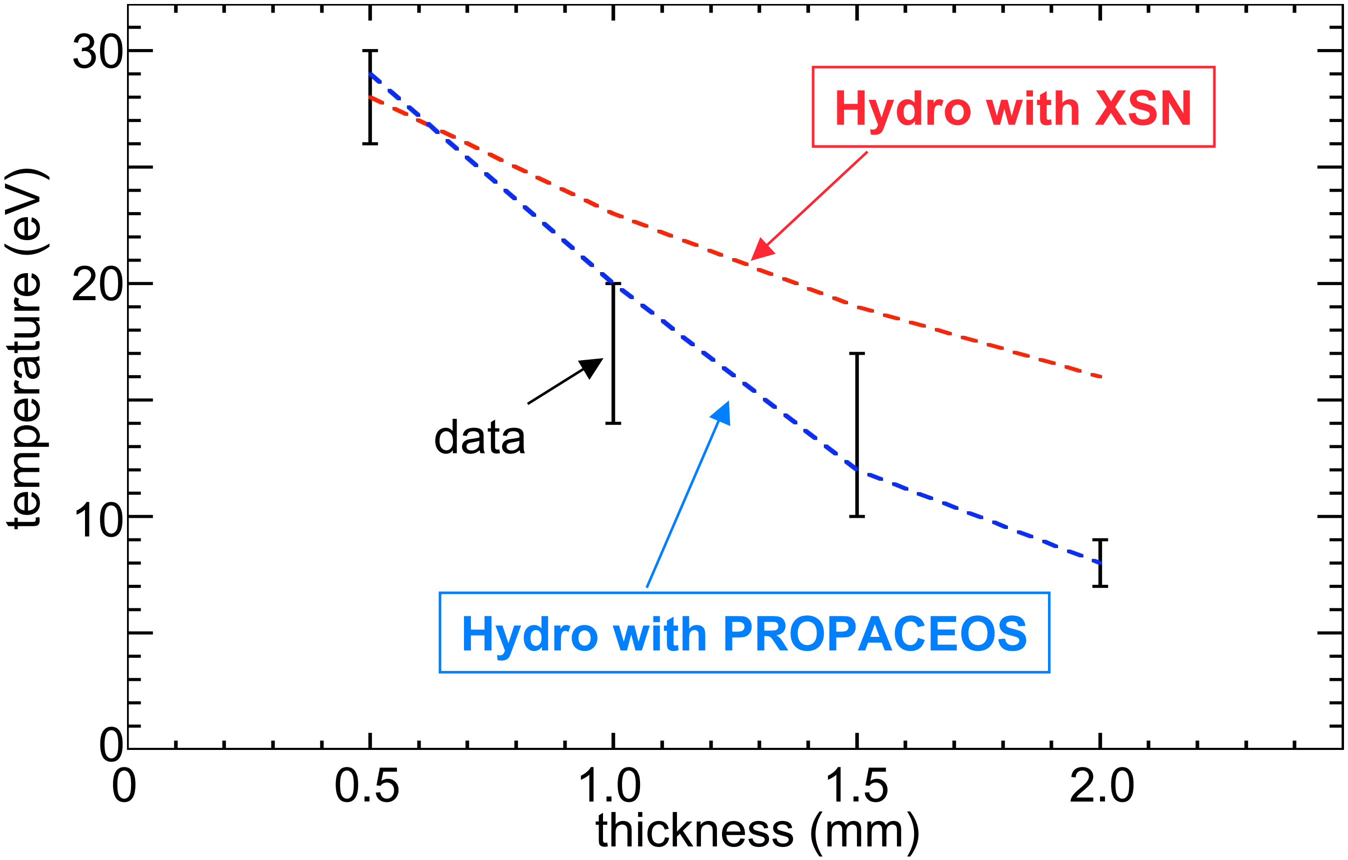
- SCO calculations by P. Arnault, T. Blenski, and G. Dejonghe (CEA France)
- J.E. Bailey et al., JQSRT 81, 31 (2003).

CH_2 foam opacity can be inferred by measuring heating of Mg foils placed behind different foam thicknesses.





Mg tracer heating behind different foam thicknesses discriminates between different CH_2 opacity models



This method is relatively indirect, but it can address a difficult to access regime

goals for future work

- Model comparisons, feature identification
- Measure transmission with multiple Fe thickness on a single shot
- Extend to shorter and longer wavelengths
- Optimize tamping and sample design with benchmarked rad-hydro simulations
- Extend to higher densities and temperatures (ZR)

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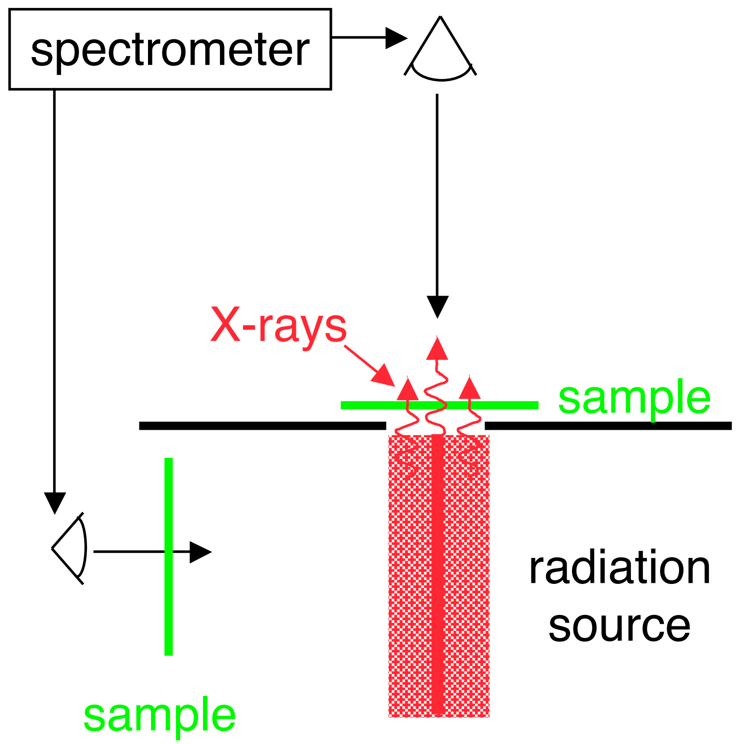
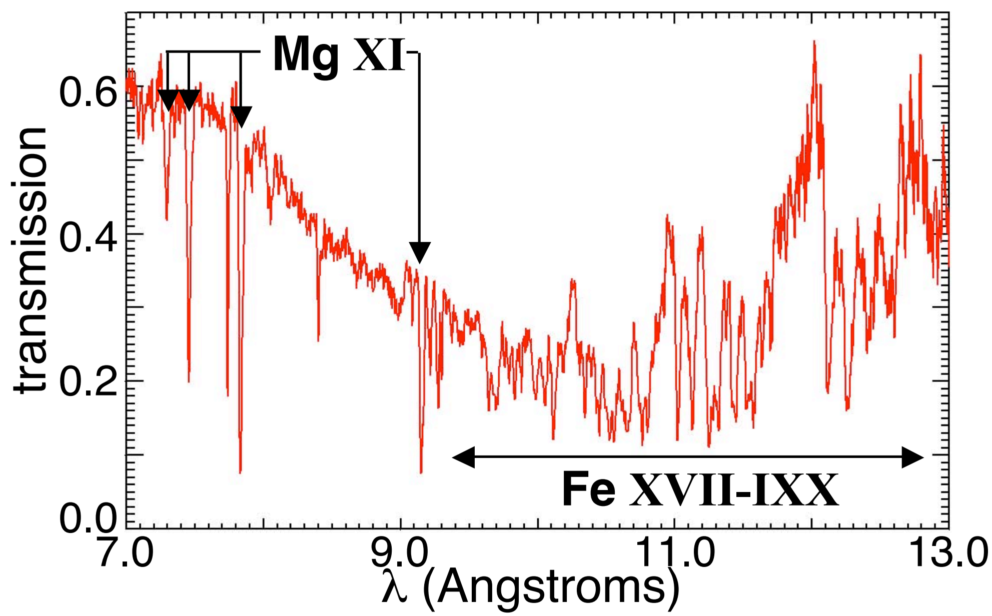
Z opacity experiments strengthen existing database and extend measurements beyond T ~ 150 eV



Fe + Mg transmission at $T_e \sim 160$ eV, $n_e \sim 10^{22}$ cm^{-3}



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